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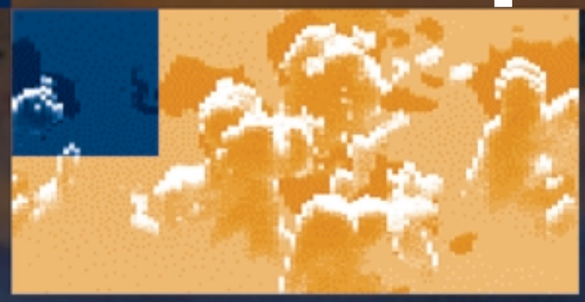
A. Marshak · A. Davis
Editors

3 D Radiative Transfer in Cloudy Atmospheres



Physics of Earth and Space Environments

Marshak · Davis (Eds.)
3 D Radiative Transfer in Cloudy Atmospheres

Developments in three-dimensional cloud radiation over the past few decades are assessed and distilled into this contributed volume. Chapters are authored by subject-matter experts who address a broad audience of graduate students, researchers, and anyone interested in cloud-radiation processes in the solar and infrared spectral regions. After two introductory chapters and a section on the fundamental physics and computational techniques, the volume extensively treats two main application areas: the impact of clouds on the Earth's radiation budget, which is an essential aspect of climate modeling; and remote observation of clouds, especially with the advanced sensors on current and future satellite missions.

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3 D Radiative Transfer in Cloudy Atmospheres

Springer

Dedication

To the memory of

Georgii A. Titov

(March 5, 1948 – July 25, 1998)

and

Gerald C. Pomraning

(February 25, 1936 – February 6, 1999)

George Titov and Jerry Pomraning (courtesy of Lucia Levermore).

"[Preliminary] Monte Carlo results are generally modulo a factor of π."

Georgii Titov

"Life is an integral!"

Jerry Pomraning

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The series *Physics of Earth and Space Environments* is devoted to monograph texts dealing with all aspects of atmospheric, hydrospheric and space science research and advanced teaching. The presentations will be both qualitative as well as quantitative, with strong emphasis on the underlying (geo)physical sciences.

Of particular interest are

- contributions which relate fundamental research in the aforementioned fields to present and developing environmental issues viewed broadly
- concise accounts of newly emerging important topics that are embedded in a broader framework in order to provide quick but readable access of new material to a larger audience

The books forming this collection will be of importance for graduate students and active researchers alike.

Series Editors:

Preface

A few years ago one of us (AM) was giving a series of lectures on three-dimensional (3D) radiative transfer in cloudy atmospheres at the Summer 1999 School "Exploring the Atmosphere by Remote Sensing Techniques" hosted by the Abdus Salam International Centre for Theoretical Physics in Trieste (Italy). By the end of the series, the instructor was asked by students for an available book on the subject. It turned out that in spite of multiple decades of research, relative maturity of the field, the involvement of dozens of scientists worldwide, and hundreds of journal papers, there was in fact no tutorial book in existence. So there was nowhere for students and young researchers to start or to use as a reference. One of the directors of the school, Rodolfo Guzzi, and the editor of the physics section of Springer-Verlag, Christian Caron, who was also there, suggested that we fill this gap by writing a monograph on the subject.

We enthusiastically accepted the Springer-Verlag commission and attracted many leading 3D radiative transfer scientists as co-authors: H. Barker, N. Byrne, R. Cahalan, E. Clothiaux, R. Davies, R. Ellingson, F. Evans, P. Gabriel, A. Heidinger, Y. Knyazikhin, A. Korolev, R. Myneni, I. Polonsky, G. Stephens, E. Takara, and W. Wiscombe. More than half of them are on the science team of the Atmospheric Radiation Measurements (ARM) program sponsored by the U.S. Department of Energy (DOE). A major goal of ARM is to further our understanding of radiative transfer in the atmosphere – especially the role of clouds – and at the Earth's surface. The DOE's ARM program has therefore provided generous funding for this book project. We also greatly appreciate the ongoing support we receive from our home institutions, Los Alamos National Laboratory and NASA's Goddard Space Flight Center, and the support received from the Joint Center for Earth Systems Technology of UMBC, where one of us worked at the beginning of the project. Technical expertise in Springer-Verlag's LaTeX desktop publishing environment was ensured by Lisa LeBlanc, now with the Canadian CLIVAR Network at McGill University; without her help, we would not have been able to prepare this manuscript.

The title of this book is "Three-Dimensional Radiative Transfer in Cloudy Atmospheres." At one point, we were tempted to use the more provocative title "*Real* Radiative Transfer in Cloudy Atmospheres." Indeed, it is the 3D radiative transfer

equation that determines the radiation processes in real cloudy atmospheres. By contrast, the standard 1D model, which can be traced back at least 100 years, is an approximation that should prove useful under certain circumstances. In other words, it is time to think of 3D theory as the golden standard in atmospheric radiative transfer rather than as a perturbation of standard 1D theory.

The book captures and preserves much of the best 3D cloud radiation work done in the last couple of decades, and brings it to better maturity as authors took special care to explain their discoveries and advances to a larger audience. Our primary readership will be made of graduate students and researchers who specialize in atmospheric radiation and cloud remote sensing. However, we hope that remote sensing scientists in other application areas (biosphere, hydrosphere, cryosphere, etc.) will find many portions of the volume stimulating.

Beyond the two introductory chapters, the volume naturally divides into three parts: Fundamentals, Climate, and Remote Sensing. The two last topics are indeed the main concerns in atmospheric radiation science. The chapters are essentially independent but cross-reference each other. We tried our best to avoid overlap; in several places, however, we found it more effective to repeat some material rather than pointing to other portions of the book. Most chapters end with Notes and/or a Suggested Reading list because they open more questions then they answer; these contain input from the authors, the reviewers, and the editors. As much as possible, we tried to use the same notation throughout the whole book. A list of notations and a subject index can be found at the end of the volume. Each chapter has been peer-reviewed by at least one reviewer internal to the author collective and one external reviewer. We wish to thank all reviewers, especially the external ones: Larry Di Girolamo, Qiang Fu, Jeff Haferman, Harshvardhan, Alexei Lyapustin, Andreas Macke, John Martonchik, Lazaros Oreopoulos, Klaus Pfeilsticker, Bill Ridgway, Tamas Várnai, and Tatyana Zhuravleva.

This project took us much longer than we initially anticipated. Being committed to other projects during the daytime, we mostly worked on the book during the evenings and weekends at home, taking time from our families. We are very grateful for their support and understanding. It was rewarding to work on this book, writing our own chapters, reading and editing other chapters. We personally learned a lot and we hope that the readers will enjoy it too.

Finally, we dedicate this book to the memory of two great radiative transfer scientists, G. Pomraning and G. Titov. We consider ourselves lucky to have met them and to have learned so much from them.

Greenbelt, Maryland *Alexander Marshak*
December, 2004 *Anthony Davis*

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